MULTIMEDIA UNIVERSITY

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 2, 2019/2020**

## EEE2146 – MICROELECTRONIC CIRCUIT ANALYSIS AND DESIGN

( All sections / Groups )

5 MARCH 2020

2:30 PM to 4:30 PM

( 2 Hours )

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**INSTRUCTIONS TO STUDENTS**

1. This examination paper consists of 6 pages with 4 questions only.
2. Attempt **ALL FOUR** questions. All questions carry equal marks and the distribution of the marks for each question is given.
3. Please print all your answers in the Answer Booklet provided.

## Question 1

(a) Draw the DC equivalent circuit of the circuit shown in Figure Q1. Apply Thevenin's theorem and compute the transistor base current, $I_B$, collector current, $I_C$ and collector voltage, $V_C$ (with respect to ground). Given that $V_{CC}$ = 10 V and the transistor $V_{BE(active)}$ = 0.7 V, current gain $\beta$ = 100 and early voltage $V_A = \infty$. Note that, $R_1$ = 150 kΩ, $R_2$ = 150 kΩ, $R_c$ = 900 Ω, $R_L$ = 50 Ω, $R_{Sig}$ = 50 Ω. [9 marks]

(b) Draw the mid-band AC small-signal equivalent circuit of the amplifier circuit in Figure Q1 using the simplified hybrid-π model, without $r_o$. [5 marks]

(c) From the small-signal equivalent circuit, determine;
(i) the small signal input resistance, $R_{IN}$, [3 marks]
(ii) the voltage gain, $A_V = \frac{V_O}{V_{IN}}$, [4 marks]
(iii) and finally, the overall voltage gain, $G_V = \frac{V_O}{V_{Sig}}$. [4 marks]
Note that, voltage equivalence of temperature $V_T$ = 26 mV.

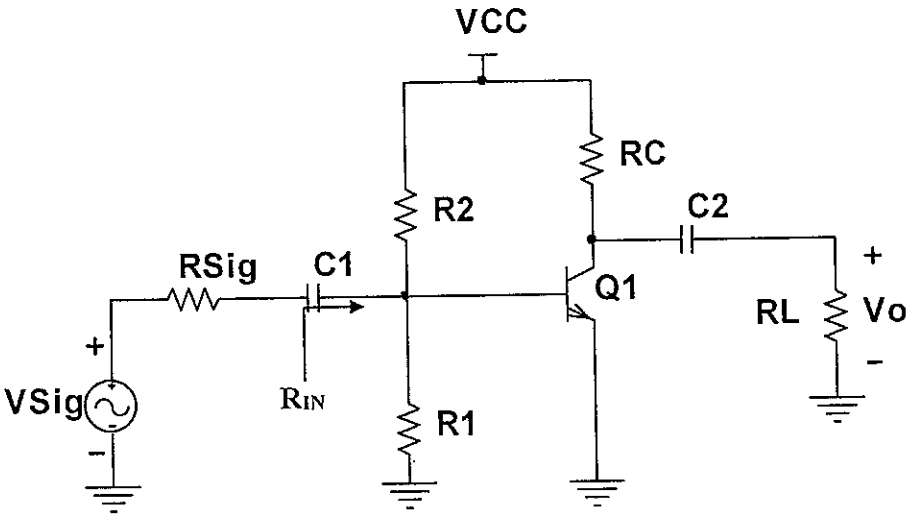


**Figure Q1**

**Continued...**

**Question 2**

The circuit shown in Figure Q2 is a common collector amplifier. The NMOS transistor has $V_t = 1.5$ V, $k'_n(W/L) = 1$ mA/V$^2$ and $V_A = \infty$. The biasing current is $I_d = 0.5$ mA. Note that, $V_{DD} = V_{SS} = 10$ V, $R_G = 10$ MΩ, $R_S = 10$ kΩ, $R_L = 10$ kΩ and $R_{sig} = 50$ Ω.

(a) Draw the DC equivalent circuit. Then, by assuming the transistor is operating in saturation region, determine the overdrive voltage $V_{OV}$, the DC gate-source voltage $V_{GS}$ and the DC source voltage $V_S$. Note that, the DC gate current, $I_G = 0$ A. [7 marks]

(b) Draw a mid-band AC small-signal equivalent circuit for the circuit shown in Figure Q2 using the simplified T model (without $r_o$). [5 marks]

(c) Refer to the small-signal equivalent circuit in part (b), determine;
(i) the small-signal input resistance, $R_{IN}$, [2 mark]
(ii) the small-signal voltage gain, $A_v = \frac{v_o}{v_{in}}$, and [7 marks]
(iiii) the overall small-signal voltage gain, $G_v = \frac{v_o}{v_{sig}}$. [4 marks]

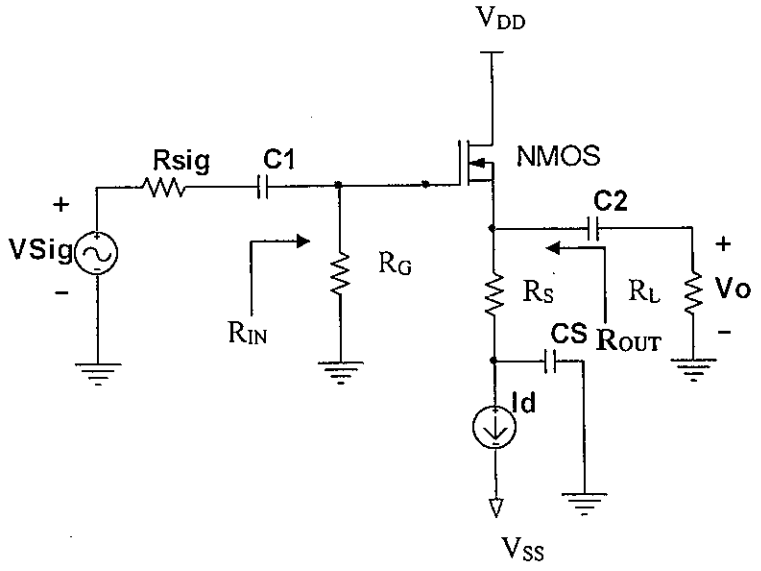


**Figure Q2**

**Continued...**

**Question 3**

Figure Q3 shows the NMOS differential amplifier with a current mirror as its biasing element.

(a) Assume all transistors are identical and in the saturation region, show that the biasing current $I_Q$ has the following expression (Hint: Focus on the current mirror). [5 marks]

$$I_q = \frac{(W/L)_3}{(W/L)_4} I_{ref}$$

(b) From the differential amplifier circuit shown in Figure Q3, draw the half-circuit for DC analysis. Then, determine the value of the resistors $R_{D1} = R_{D2} = R_D$ for the differential amplifier shown in Figure Q3 when $V_{DD} = V_{SS} = 12$ V, the biasing current $I_q = 200$ μA and $V_{DS} = 7$ V. Assume that all the transistors are identical and $k'_n(W/L) = 5$ mA/V$^2$, $V_{th} = 1$ V and early voltage $V_A = \infty$. [10 marks]

(c) From the differential circuit shown in Figure Q3,

(i) draw the differential-mode half circuit, and, [2 marks]

(ii) its corresponding small signal equivalent circuit (without $r_o$). [2 marks]

(iii) Finally, prove that the small-signal differential-mode voltage gain of the differential amplifier shown in Figure Q3 is as follows; [6 marks]

$$A_d = \frac{V_{od}}{V_{id}} = -g_m R_D.$$

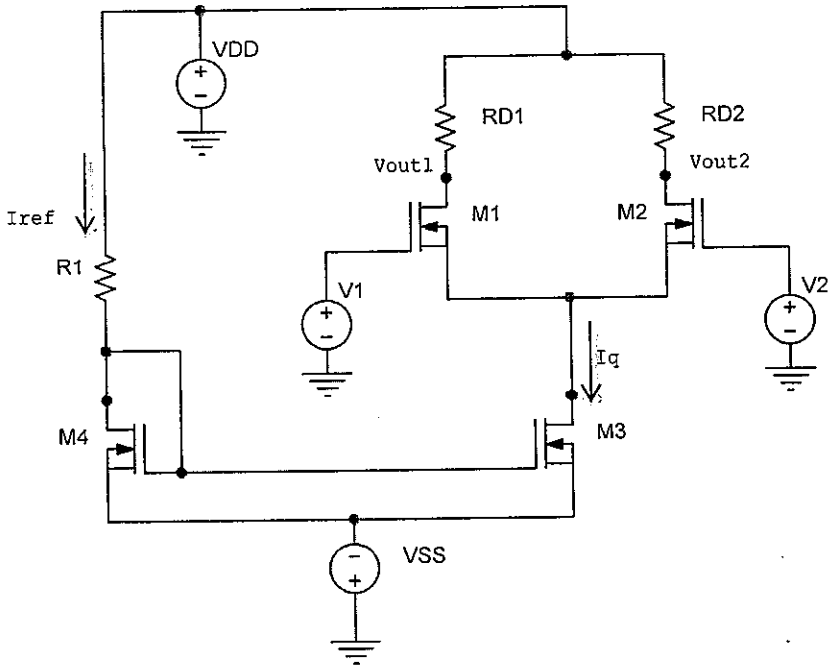


**Figure Q3**

**Continued...**

## Question 4

(a) Evaluate the effect of capacitor $C_1$ at low frequency in Figure Q4(a) circuit.

(i) First, draw a small signal equivalent circuit using hybrid-π model at low frequency. Note that, the transistor output resistance, $r_o = \infty$. [3 marks]

(ii) Then, draw a small signal equivalent circuit showing the effect of $C_1$ only. [2 marks]

(iii) Next, draw a small signal equivalent circuit with some modification to the circuit drawn in (a)(ii) to derive the lower cutoff frequency, $f_{cl}$ of the circuit. [2 marks]

(iv) Finally, derive the low cutoff frequency due to $C_1$. [5 marks]

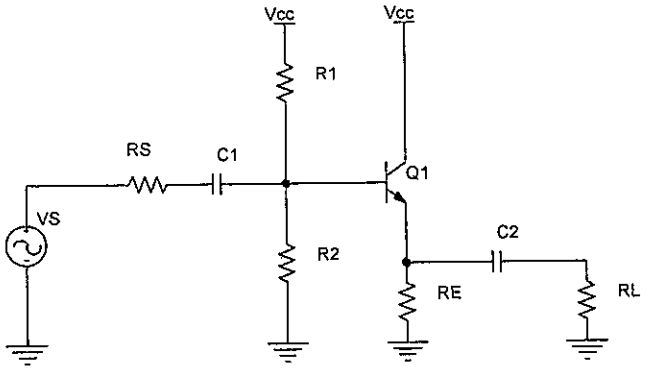


**Figure Q4(a)**

(b) An ideal series-shunt feedback amplifier can be represented by the equivalent circuit shown in Figure Q4(b). Derive the equations for $A_f$, $R_{if}$ and $R_{of}$. Evaluate the effect of feedback as compared to the main amplifier characteristic ($A$, $R_i$ and $R_o$) of A circuit, state whether the feedback can increase or decrease the main amplifier $A$, $R_i$ and $R_o$.

[13 marks]

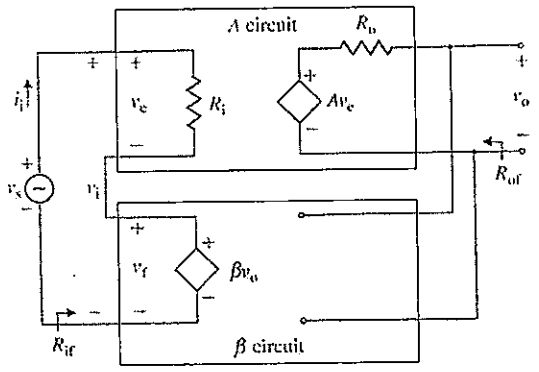


**Figure Q4(b)**

**Continued...**

## Appendix: Useful formula

$$\beta = \frac{I_C}{I_B}$$

$$\alpha = \frac{I_C}{I_E}$$

$$\alpha = \frac{\beta}{\beta+1}$$

$$\beta = \frac{\alpha}{1-\alpha}$$

$$r_e = \frac{V_T}{I_E}$$

$$\alpha = g_m r_e$$

$$r_\pi = (\beta + 1) r_e$$

$$V_T = \frac{kT}{q} \approx 26\text{mV}$$

$$I_C = I_S\left(\exp\left(\frac{V_{BE}}{V_T}\right) - 1\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$

$$g_m = \frac{\partial I_C}{\partial V_{BE}} = \frac{I_C}{V_T}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{\beta V_T}{I_C} = \frac{V_T}{I_B}$$

$$r_o = \frac{1}{\partial I_C / \partial V_{CE}} = \frac{V_A}{I_C}$$

$$g_m v_\pi = \beta i_b$$

$V_{DS} < V_{GS} - V_t$:

$$I_D = k'\left(\frac{W}{L}\right)\left[(V_{GS} - V_t)V_{DS} - \frac{1}{2}V_{DS}^2\right]$$

$V_{DS} > V_{GS} - V_t$:

$$I_D = \frac{k'}{2}\left(\frac{W}{L}\right)(V_{GS} - V_t)^2$$

$V_{DS} > V_{DS(SAT)}$:

$$I_D = \frac{k'}{2}\left(\frac{W}{L}\right)(V_{GS} - V_t)^2(1 + \lambda V_{DS})$$

$$V_A = V_M = L_{eff}\left(\frac{dX_d}{dV_{DS}}\right)^{-1} = \frac{1}{\lambda}$$

$$r_o = \frac{V_A}{I_D}$$

$$\phi_f = \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right)$$

$$\gamma = \frac{\sqrt{2q\varepsilon N_A}}{C_{ox}}$$

$$V_t = V_{to} + \gamma\left(\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f}\right)$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

$$k' = \mu_n C_{ox}$$

$$V_{OV} = V_{GS} - V_t$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = k'\frac{W}{L}V_{OV} = \frac{2I_D}{V_{OV}}$$

$$C_{gs} = C_{gd} = \frac{C_{ox}WL}{2}$$

$$I_D = I_t\frac{W}{L}\exp\left(\frac{V_{OV}}{nV_T}\right)\left[1 - \exp\left(\frac{-V_{DS}}{V_T}\right)\right]$$

**End of Paper**